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Developed during World War II, the systems approach evolved rapidly after the war into several new phases, one of which is program budgeting. There is no clear set of rules constructed along do-it-yourself lines associated with the systems approach. There are, however, general procedures which are to be followed. The first step, defining the problem, includes four distinct phases: Defining the system's objectives, obtaining measures of effectiveness, identifying constraints and uncontrollable variables, and identifying controllable variables. After defining the problem, the next three basic steps are to define the subfunctions, to define the alternatives for each subfunction, and to synthesize the subsystems. Next a model should be developed. Although a model is an abstraction, it is also a highly effective way of coping with reality, and its development calls for and guides data collection. The model must prove itself by predicting results reasonably well. However, in complex situations perfect prediction is rare and the whole system must continually be reexamined and changed as necessary. (HW)

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SYSTEMS ANALYSIS IN OUR SCHOOLS AND COLLEGES

By JOHN PFEIFFER

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NEW LOOK AT EDUCATION

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SYSTEMS ANALYSIS IN OUR SCHOOLS AND COLLEGES

BY JOHN PFEIFFER

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Chapter 2
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FOREWORD

THERE IS A NEW phrase going around education these days. It goes like this—"Now that we have achieved education for *all*, let us seek education for *each*." It is true that, while this country has reached the goal of universal education, it has yet to provide truly individualized instruction for all our young people.

It is imperative that mass education not become depersonalized education. The child must not become lost in a colossal system of fifty million others, or else we will reap a harvest of dropouts and disenchanted youths on a much larger scale than we have at present.

We have it within our grasp to achieve "education for each," but to do this will call for a newer and higher order of planning than we have so far brought to the process. Educators are exploring more effective programs for disadvantaged students, assessing innovative teaching practices such as audio-visual instruction, team teaching, nongraded schools, programmed instruction, independent learning, and are devising new methods of scheduling classes for more appropriate course offerings for each student. We must go further in accumulating orderly and meaningful school records on pupils, and in using these data for better counseling and guidance in each grade and at each level in the educational process.

Also, with the rising cost of education, we shall need to seek more efficient and productive ways of running

our schools and colleges, so that we know more accurately what we are getting for our money as we seek that level of quality which we all desire so much for our children. This is known in the jargon as "more bang for the buck," and, with present expenditures of sixty billion dollars for our schools and colleges, it is a not unimportant consideration.

Fortunately, there would appear to be a way out. Though analogies are never perfect, in the last decade both the military and business establishments, each dealing with people and dollars, have taken a hard look at improved administration, individual productivity, and the cost-effectiveness of their operations, using methods that have come to be known as operations or systems analysis. Quite simply this means that, rather than merely collecting information and statistics on the state of affairs as it is now, data are explored on a wide assortment of choices and alternatives to suggest better courses of action than current practice. The objective is imaginative and effective decision-making, and the steps are three: setting goals; seeking alternatives; evaluating results.

Recognizing the applicability of operations analysis to education, the U.S. Office of Education called a conference in late November 1967 in Washington to which some five hundred were invited. Surprisingly over a thousand attended from schools, colleges, and universities across the country. The discussions of useful applications of the scientific method ranged from site locations of urban schools, to bussing schedules, to measuring student achievement, to the education of disadvantaged children.

One of the most valuable outcomes of these sessions was the dispelling of some myths about the computer

as a control instrument over individuals and over the educational process. Basically the computer was put in its proper place, as the handmaiden not the master of education. People still make the final decisions, but wiser decisions based on alternatives rather than a single approach to the solution of a problem.

It must be said that a system does not, of and by itself, produce better education. It should, however, if used seriously, present educators wth the opportunity to face up more exactly to what they want to achieve, a program of how they hope to go about it, and the *courage to assess honestly the outcomes of their actions.*

This fascinating book deals with the whole subject of how one can be more systematic in his approach to problem analysis, no matter what the enterprise or endeavor—operating a hospital or an army base, establishing flight patterns or controlling traffic flow, or running a school or college. Where other books on this subject lean heavily to the technical or theoretical, this one provides a variety of specific illustrations of the use of systems analysis. It is comprehensive and comprehensible.

I commend this book to all educators, educators-in-training, and even to the layman who, apart from his interest in education, would like to take a look ahead at the promise which lies in the improved methods of planning to meet many of the problems of our society.

Princeton, New Jersey
February, 1968

Henry Chauncey, President
Educational Testing Service

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CHAPTER 2

DECISION MAKING IN ACTION

THE SYSTEMS APPROACH arose in response to the same demands which brought about the development of radar, rockets, nuclear weapons, and antibiotics. It is an outgrowth of procedures developed by professional teachers for professional fighters during the early days of World War II. Teams made up mainly of biologists, mathematicians, and physicists were mobilized from classrooms and laboratories to help design software instead of hardware, plans instead of equipment, first in the Battle of Britain and later in all major campaigns. They used their methods of learning, rather than their specialized knowledge, in the cause of improving military tactics and strategies.

Their work justified itself from the very beginning. There were a great many ways of improving air defenses in the Battle of Britain—selecting the most favorable locations for fighter bases and radar installations, providing increased training for pilots and maintenance crews, establishing better communication and control systems, and so on. The problem was to determine the best "mix" of these alternatives, taking the fullest advantage of radar and other innovations

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and allocating limited resources as efficiently as possible while the enemy mounted his attack. The job was accomplished with the aid of half a dozen professors attached to Fighter Command. Decisions based on their analyses doubled the chances of fighter planes intercepting Nazi bombers, thereby in effect doubling the power of the Royal Air Force.

Another early study led to notable successes in the air war against submarines, to the surprise of many military experts who agreed with Admiral Doenitz, Commander-in-Chief of the Nazi U-boat fleet: "An airplane is no more an enemy of the submarine than a crow is an enemy of the mole." One famous analysis ran directly counter to the established practice of dropping depth charges set to explode a hundred feet beneath the surface, indicating that a shallow setting of twenty to thirty feet would prove far more effective. The change was made, after some opposition, and increased the number of U-boats sunk by more than fifty percent.

The lesson of these and subsequent investigations was not forgotten when the fighting stopped. They had demonstrated for the first time on a large scale that something new and extremely significant is created by the establishment of a working relationship between decision maker and systems analyst. The decision maker can act on his own, as he often must during a war and other emergencies; indeed, under such conditions his experience and judgment may provide the only basis for action. But whenever possible he should also draw on the systems approach, because sometimes even intuition can go wrong. (For example, the policy of setting depth charges for deep detonation in air attacks actually reduced chances

of destroying a submerged U-boat to about one in a thousand, thus practically insuring the submarine's escape.)

Program Budgeting, RAND, and McNamara

The approach evolved rapidly after the war. It was applied to broader and "sloppier" problems involving greater uncertainties, more complex mixes of long-range defense-attack strategies, and objectives which were difficult to define. One phase of the systems approach, known as program budgeting, was to receive special attention in Washington. Program budgeting may be regarded as a way of organizing cost data in such a manner that they can be used to analyze different courses of action in terms of cost and utility. Program budgets indicate specific purposes and methods of carrying them out, in sharp contrast to conventional budgets which indicate general categories only and tell little about plans and objectives.

For example, a conventional federal transportation budget might include a "Water transport" category and list under it the requirements for the Department of Commerce, the Coast Guard, and the Interoceanic Canal Commission. "Aviation" and "Highways" categories would be broken down in similar fashion. A program budget, on the other hand, would cut across formal organizational lines and show precisely how and why money is to be spent. One major category might be "Improve intercity transport," and expenditures for various innovations in aviation, highway design, and water transport might all be listed under that heading.

An analogous budget for a school system or university would emphasize programs of instruction, special

as well as regular programs, and the facilities and plans proposed for future improvements in each program. Furthermore, like all program budgets it would look ahead five to ten years instead of only a year or so as in conventional budgets. It should be pointed out that the conventional budget, which generally involves such major categories as maintenance, transportation, supplies, and salaries, also has its uses for legal and practical reasons. With its emphasis on objectives and alternatives and precise evaluation, however, program budgeting is expected to see wider use as the systems approach is itself used more widely.

The history of program budgeting may be traced back twenty years to the "performance" budgeting of the Hoover Commission for Reorganization of the Executive Branch and, before that, to studies of public administration conducted during the 1930's and earlier. But the most intensive and original applications after World War II were made under military auspices, particularly at the Air Force sponsored RAND Corporation in Santa Monica, California. In fact, the organization recommended program budgeting to the Air Force as early as 1953, and the suggestion was received with what has been officially described as "something less than complete enthusiasm."

Enthusiasm and acceptance came seven years later when Secretary McNamara met Charles Hitch, one of RAND's leading exponents of program budgeting, and invited him to help reorganize planning and budget procedures at the Department of Defense. Hitch accepted, bringing with him several of his RAND associates as well as a number of analytical techniques for evaluating plans and strategies, the objective being to get the most out of given and limited resources. One

of the first important jobs of the new team was an analysis of an Air Force proposal for an additional wing of B-52 bombers and the production of nuclear powered B-70 bombers equipped with Skybolt rockets. By the fall of 1961 Secretary McNamara had received a set of reports which indicated that alternative measures might meet future strategic demands more effectively, and he took immediate action against production of the bombers.

These and subsequent studies have had a great influence on the shaping of the nation's military policies—the shift of emphasis from bombers to missiles, the reduced vulnerability of deterrent forces, the increase of tactical air forces in Army divisions. In almost every case the prospect of change aroused concern and opposition, as it always does, but this did not discourage attempts to assess the comparative costs and effectiveness of doing things differently. In other words, the decisions finally arrived at were based on calculated trade-offs and the weighing of alternatives as well as on individual intuition and judgment.

The success of such procedures was striking. Indeed, it was so evident that in the summer of 1965 the White House issued an executive order to the effect that from then on measures like those used in the Department of Defense were to be used in evaluating programs proposed by other federal offices and agencies. One result, of course, has been to establish the systems approach as a matter of national policy. Even more significant, the order represents official recognition of the fact that in a fundamental sense civil rights, the war against poverty, and other nonmilitary issues have attained an urgency comparable to that of military programs, which after all is something new.

A "How To" Approach for Educators

This may be a good point to take a closer look at things. As the systems approach comes into prominence, educators and others will have increasing occasion to consider it in somewhat greater detail. We have already emphasized that they will not find a clear-cut set of rules or a step-by-step framework constructed along do-it-yourself lines. We would be proceeding under false pretenses if we presented the approach as other than a thing in process, rather fuzzy at the edges perhaps, but embodying a core of procedures which can be identified and used to good effect.

The rest of this chapter is based largely on discussions with Alfred Blumstein of the Institute of Defense Analyses in Arlington, Virginia. Recently he served on the President's Commission on Law Enforcement and Administration, known as the President's Crime Commission, as director of a special task force organized to indicate how science and technology can play a far greater role in combating crime than is the case at present. The report of the task force emphasizes possible contributions of the systems approach, and during the study Blumstein became increasingly aware of the value of the approach in education, among other areas.

At a meeting held in the spring of 1967 Dr. Blumstein participated in discussions with Mark Shedd, superintendent of the school district of Philadelphia; and David Horowitz, associate superintendent in charge of the office of planning. During the course of the discussions he outlined a version of the systems

approach which is essentially that outlined in the following paragraphs. It covers a whole range of procedures from defining the problem and basic objectives to the selection of one of a number of courses —all part of a sophisticated and disciplined way of thinking about plans and alternatives.

Defining the problem is almost a stylistic thing, calling for a certain simplicity of design. It is to some extent a pruning and clearing and lopping-off operation, an intense effort to eliminate trivia and secondary issues, and to concentrate on basic relationships. It means obtaining a clear picture of the dimensions of the problem, understanding the rules of the game—and that may not always be as easy as it sounds. It is actually a complex procedure which includes four distinct phases.

1) *Defining the system's objectives.* Sometimes a project can bog down or fail completely because the planners decided on the wrong objectives. To cite only one example the effectiveness of naval defenses increased enormously early in World War II when it was decided to concentrate on protecting Allied shipping and sea lanes rather than on sinking U-boats (the original major objective). A poorly chosen or poorly defined objective can nullify the efforts of the best administrators.

2) *Obtaining measures of effectiveness.* Measuring the wrong things may be as unproductive as selecting the wrong objectives. Appropriate yardsticks are essential to setting goals, making improvements on schedule, and keeping tabs on how closely the schedules are being met.

3) *Identifying constraints and uncontrollable variables.* Since every system is part of a larger system, there will always be things that do not change and can-

not be changed in any reasonable period. These are known as constraints and range from fixed budgets and existing rules and laws to firmly established traditions which serve a real purpose or which have little value but are not yet ripe for breaking. Uncontrollable variables include things like the weather and population trends, which may indeed undergo spectacular changes but are not normally under the decision maker's control.

4) *Identifying controllable variables.* The decision-maker is naturally concerned above all with introducing innovations and hastening or slowing the pace of events, with those elements which he can change "to order" in his efforts to get results.

Once the boundaries of a problem have been clearly marked out, the emphasis is on planning possible courses of action. Every problem has a number of subobjectives or subfunctions which must be considered in the process of achieving the major objective. Furthermore, there are generally a number of different ways of carrying out each subfunction and of bringing it into a better relationship with other parts of the total system. An important part of the systems approach is to specify the subfunctions and the alternatives, and then to build them into total systems which can be evaluated and compared in terms of basic objectives.

For example, suppose the major objective of a public safety program is to reduce traffic accidents. One might define three subsystems: the drivers, the vehicles, and the highways. As far as improving the driver is concerned, accidents might be reduced by punishing traffic violations more severely, administering more frequent eye examinations, requiring more training at driving schools, and so on. Less powerful engines, more thorough factory inspection, dashboard padding, and antiglare windshields are among the

ways of making cars safer; while highway safety features include properly banked curves, larger and more frequent signs, and improved lighting.

Many subsystems can be built from all these factors and they must be investigated if we want to learn which combination of driver, automobile, and highway characteristics will result in the fewest accidents (assuming, of course, that for various reasons not all safety steps can be taken). The process as outlined so far may be represented in the following diagram:

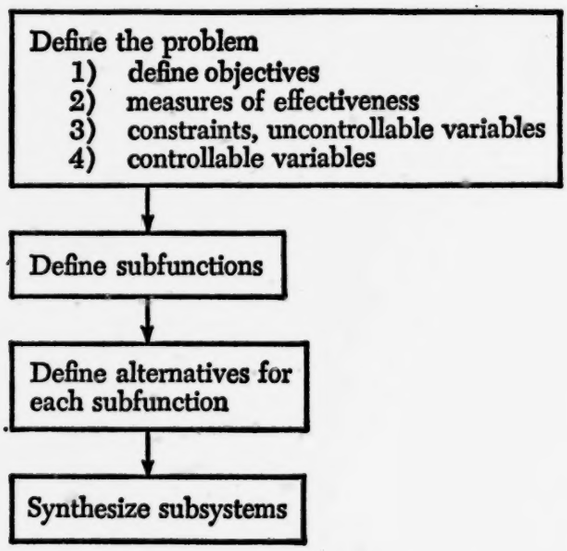


Table 1 indicates in a rough way how the systems approach has actually been applied in the analysis of four situations. Although synthesized subsystems are not included, the variety of possible combinations is evident. The antisubmarine example has been taken from reports on the development of strategies in the

TABLE 1. SOME SYSTEMS APPROACH ELEMENTS

	Antisubmarine Air Patrol 1940	*Air Traffic Control 1960*	*Criminal Apprehension 1967*	*Urban Education 1970?*
Objective	destroy submarines	prevent collisions	decrease crime	improve education, esp. of students in lowest socioeconomic bracket
Measures of effectiveness	probability of sinking, number of flying hours per kill, etc.	probability of collision, delay, cost	probability of apprehension, time from crime to police arrival at scene	proportion graduating from high school (current proportion: 20% of the lowest quartile)
Constraints and uncontrollable variables	weather, submarine characteristics, range and speed of planes, etc.	weather, traffic load, reaction times, etc.	speed of patrol cars, limitations on search, calls for police service, reaction times	state curriculum requirements, student enrollments, salary regulations
Controllable variables	intelligence operations, number of planes, technological changes, etc.	separation of planes, technological changes, etc.	technological changes, number of complaint clerks, number of police cars, etc.	technological changes, extracurricular programs, programs for parent involvement, location and size of schools
Subfunctions	detect submarine; destroy submarine	detect plane positions; generate control orders; communicate orders	detect crime; dispatch police to scene of crime; travel to scene of crime	forecast future needs; provide teaching staff; transmit information
Alternatives	detect: radar, visual, magnetic devices, patrol destroy: mines, depth charges, rockets	detect: radar, visual, pilot reports orders: time separation, distance separation communicate: flashing lights, voice radio, radio signals to auto-pilot	detect: patrol units, alarms, victims and witnesses dispatch: public call-boxes, radio networks, dispatchers, computer command and control travel: patrol cars, helicopters, scooters	forecast: pop. trends, political pressures, technological changes provide: mix of teachers and teacher aides, in-service training, teacher-student ratio transmit: conventional classrooms, individual instruction, computer-assisted learning

North Atlantic. The air-safety example is based on a study published in 1960 and discussed at the meeting with Mark Shedd and David Horowitz. The police-arrests study is part of the 1967 report of the President's Crime Commission. Finally, the example involving education is only preliminary, being included to indicate future possibilities.

Developing Systems Analytical Models

This is not the full story, of course. The diagram on page 24 represents only a bare outline of what actually goes on. In its present form it does not include the use of a model, which is essential not only to the systems approach but also to any scientific effort to understand events. A model has an interesting and significant double aspect. As has already been pointed out in the last chapter, it is an abstraction—a highly simplified version of a fragment of the real world which is too complex for us to deal with directly. At the same time, however, it is one highly effective way of coping with reality.

Subsequent chapters discuss a number of models in some detail. Here we shall simply emphasize certain limitations and advantages, and the general role of the model in the context of systematic inquiry.

For example, scientists recently made use of a miniature earth, a magnetic steel sphere about the size of a softball. They placed it in a sealed vacuum jar, produced an intense electric field such as might be caused by sunspots, and created a bluish circle of light over the sphere's north pole—a small-scale northern lights display. This experiment is part of a long-range study of the upper atmosphere in general, and of spacecraft communications blackouts in particular

since auroras may interfere with radio reception. It happens to involve an obvious physical model. But models can be of varying types and of varying degrees of abstraction. An experiment may be designed to investigate the effects of a new drug on cancer cells, the behavior of rats in a maze, or the primitive chemical conditions under which life on earth may have originated. The investigator selects as his model some narrow aspect of the real world and subjects it to carefully controlled changes, which will hopefully produce effects that are significantly related to effects in the real world at large.

The same expectation applies to more abstract models, such as those consisting of mathematical equations, which express simplified and formal concepts about natural phenomena. In any case a model is meant to clarify, and to yield information. That depends on how well it is designed. It will certainly be modified or superseded sooner or later in the light of accumulating knowledge, which is the general fate of models. Indeed, from one standpoint the role of a good model is to speed its own obsolescence. It cannot provide final answers and is not intended to. It has served its purpose if it provides fresh insights into the working of things.

In the systems approach the development of a model proceeds along with the already outlined steps leading from the definition of the problem to the synthesis of subsystems. The first version may be merely a rough flow chart indicating the sequence of these steps, like the diagram earlier in this chapter. That version, and subsequent refinements of it, serve, among other things, to indicate gaps in our knowledge and point toward the sort of data needed to fill

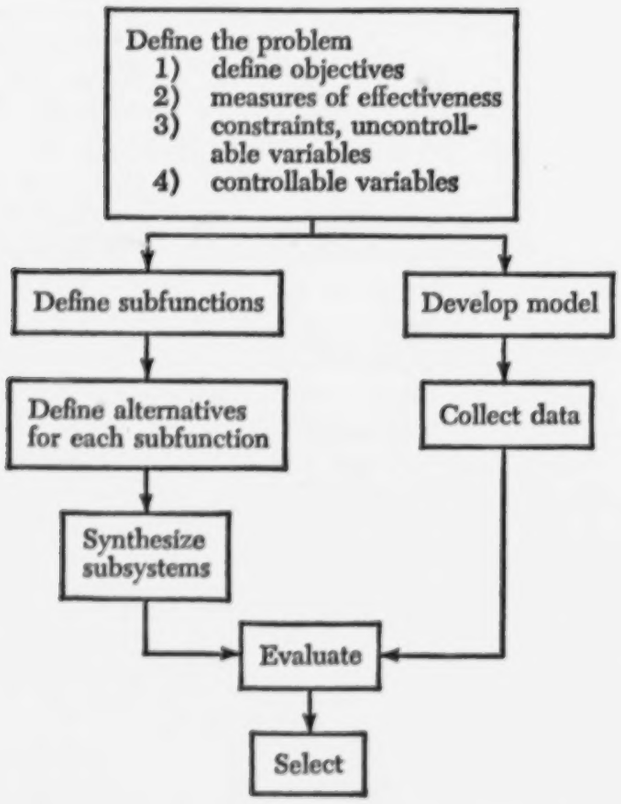
the gaps. This is a most valuable function. There is no more futile activity in science than the dogged accumulation of facts in the hope that meanings will somehow arise spontaneously once a certain critical data mass has been achieved.

So the development of a model calls for and guides the collection of data. There can be nothing superficial or perfunctory or remote about this phase of the process. People working in the systems field speak of "grubbing around in the data," which means just what it says—digging down to the roots of things, searching out, getting your hands dirty. The investigator must go where the action is, into the schoolroom or hospital ward or jail or battlefield. He must often make something of a nuisance of himself by asking questions and more questions, until he discovers what people do not know as well as what they do know.

Flow Charts and Models

The data must be gathered, organized, analyzed, and then used to evaluate—often by cost-benefit studies—innovations and the combinations of innovations included in alternate subsystems—which is just where program budgeting may come into the picture, together with an assortment of related techniques. These added steps may be represented in a more detailed version of our previous diagram as shown on page. 29.

This is a fuller but still incomplete flow chart, and the missing element represents a basic characteristic of the systems approach. The act of selection is shown as the end of a step-by-step process, when it should be the beginning—or, more accurately, it should be regarded as part of a cyclical and continuing process.



The preparation of an initial study—defining alternatives and subsystems, building models, and analyzing data—may result in a selection as indicated in the diagram. But more often than not the evaluation itself leads to further studies, which eventually lead to further and more sophisticated selections.

The systems approach must prove itself by predicting results reasonably well. It says in effect that if

you take a certain course of action certain things will happen, and on occasion it may predict with impressive accuracy. Military experience provides one notable example of success forecasting, again involving air patrols against submarines during World War II. This time the analysis concerned operations in the Bay of Biscay and indicated that two submarines would be sunk per week if twenty-five extra bombers were added to the patrol. After some argument the bombers were provided reluctantly for a trial period of three weeks, during which exactly six submarines were destroyed.

It would be convenient if all outcomes could be predicted as neatly. But the case of the submarine patrol is one that permits rather precise studies because, although there is definitely a human element, it involves machines and other physical devices predominantly—and it has been observed that the combination of a man and a machine behaves more like a machine than a man. In other words, precise forecasts are possible in any situation which, like that prevailing in the Bay of Biscay campaign and in certain industrial contexts, leans heavily on the use of machines in carrying out its operations.

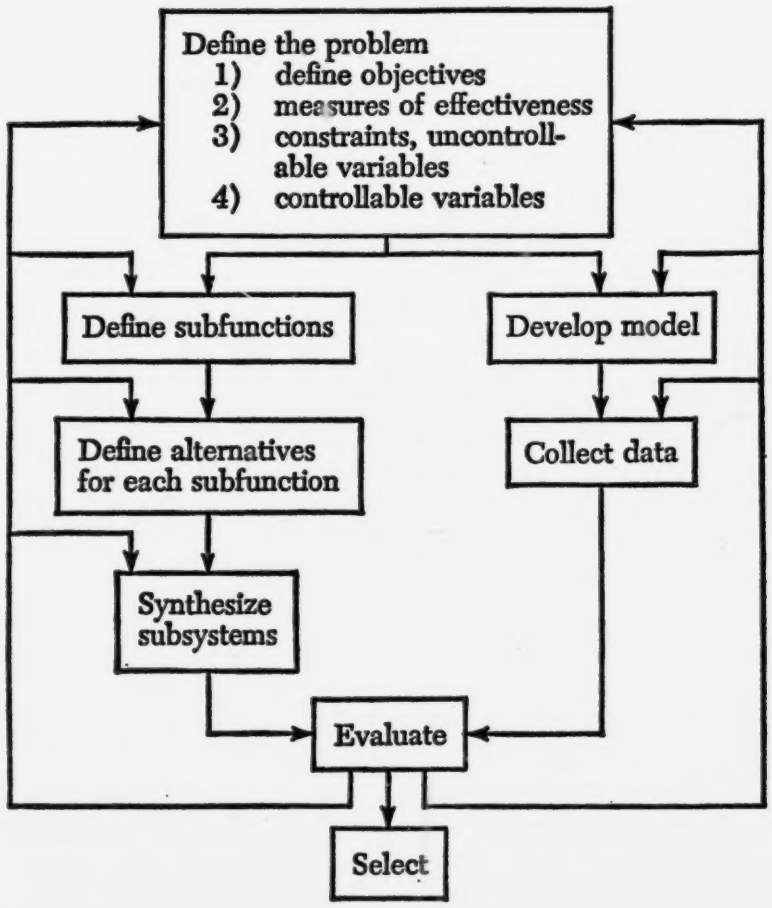
Precise forecasts are rare in more complex military and industrial situations, and even rarer in education, health and welfare, and other public areas. The systems approach reflects the fact that uncertainty increases inevitably as machines become less important than the human element, that a certain amount of sloppiness is part of the nature of all vital and evolving things. This is why selections must be tentative and why the predictions upon which they are based must be checked and re-checked.

Refining the Model

The problem is how much the model is off, how much it departs from reality—and the deviation demands new analyses to provide more realistic, more precise, predictions. That means re-examining assumptions at all levels, along the subsystem-alternatives-subfunctions and data-model channels, and discovering and making appropriate changes. It may even be necessary to make changes at the uppermost level to transform an uncontrollable into a controllable variable or devise new measures of effectiveness or re-define objectives. All this means readjusting models, new evaluations, and new selections as the feedback cycle proceeds. So our final flow chart, with feedback channels included, takes the form shown on page 32.

An enormous amount of experience and trial and error has gone into the development of such procedures. "The critical art in the beginning," Blumstein emphasizes, "is knowing where to truncate or cut short, where to avoid side issues and bring your thinking to bear on the really important and interesting controllable variables. These variables are our levers on the real world; we can first manipulate them in our model world and see what happens. Then we are better prepared to organize the real world and make things happen there. We are creating structures."

The systems approach is one of the newest and most rapidly evolving phases in man's attempt to make order out of chaos, or near-chaos. We seem always to be teetering on the edge of complete catastrophe; indeed, there is at least a fighting chance that we



may yet achieve complete catastrophe. But if we manage to avoid it, it will be because we have learned to deal in a disciplined manner with our biggest problems, to impose a rational structure on phenomena whose structures are not immediately apparent. In this effort the systems approach will assume increasing prominence.